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Current Status and Future Directions in the Use of High-Resolution Atmospheric Models for Support of T&E

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Weather Forecasting as a High Performance Computing problem

- *The world's first electronic computer (ENIAC*) was developed by "Army Ordnance" (Aberdeen Proving Ground) to compute World War II ballistic firing tables.*

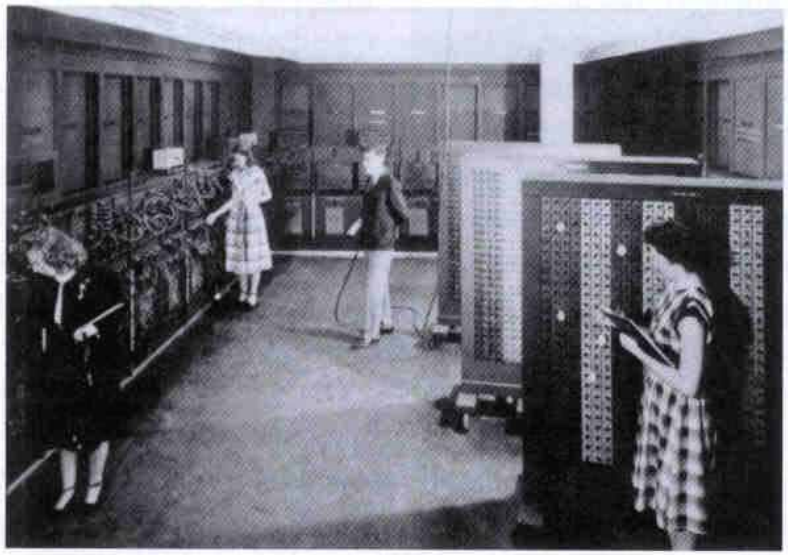


Figure 3: The ENIAC computer in 1948. The operators are changing the plug-in wiring. (PLATZMAN, 1979).

- *In addition to ballistics, the ENIAC's fields of application included weather prediction...*

*Electronic Numerical Integrator And Computer

More recent indicators of weather's dominant role as a user of high-performance computing

- 1952 - Princeton's Institute for Advanced Study developed first general-purpose computer; the primary intended use was weather prediction and research
- 1977 - The National Center for Atmospheric Research was Cray Research's first official customer with the Cray 1A
- 2000 – Europe's three fastest super computers were dedicated to weather forecasting
- 2005 – 10-20 of the top-100 super computers in the world are utilized primarily for operational weather forecasting or weather research

Why Numerical Weather Prediction is Computationally Intensive

- Nonlinear, nonhomogeneous, partial differential equations that describe fluid dynamics and thermodynamics of the atmosphere must be solved with high-order numerical techniques
- Physics of atmospheric turbulence, radiation, chemistry and cloud/precipitation processes are complex
- Soil, vegetation, ocean processes are part of model
- Because of the numerics, a doubling of the resolution in horizontal and vertical requires a 16-fold increase in the computing power required for the same area

History of ATEC Four-Dimensional Weather (4DWX) Program

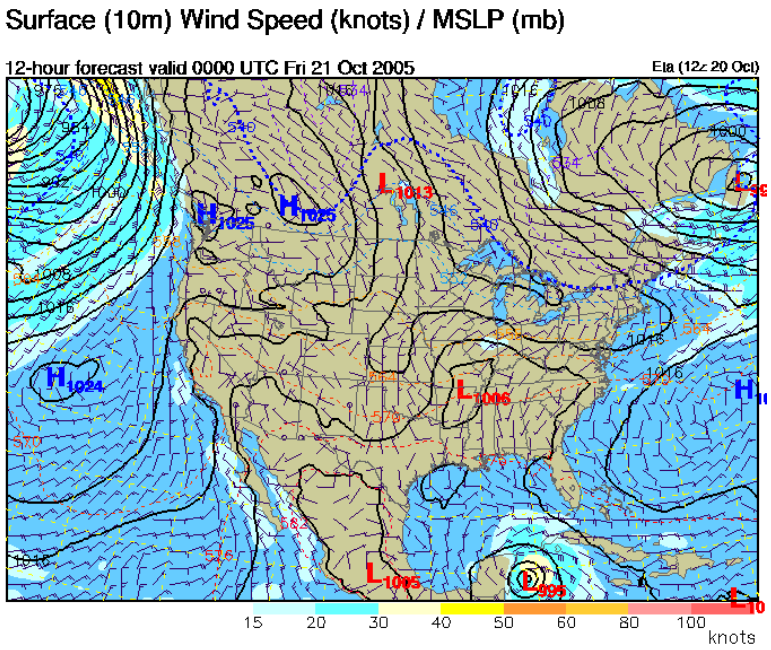
- Situation in 1995 – Unmet needs of Army test range forecasters
  - range-scale model products,
  - a modern data archival system, and
  - better graphical displays of data and model products
- 1996-present – ATEC and the National Center for Atmospheric Research have partnered on the development of one of the highest-resolution operational weather-prediction systems in the world

Paradigms of the ATEC 4DWX Program

- Partnership and close collaboration between ATEC meteorologists and system developers
- Rapid prototyping and deployment of new capabilities – concept to operations in 3-6 months
- Frequent upgrades/releases – system is NOT static

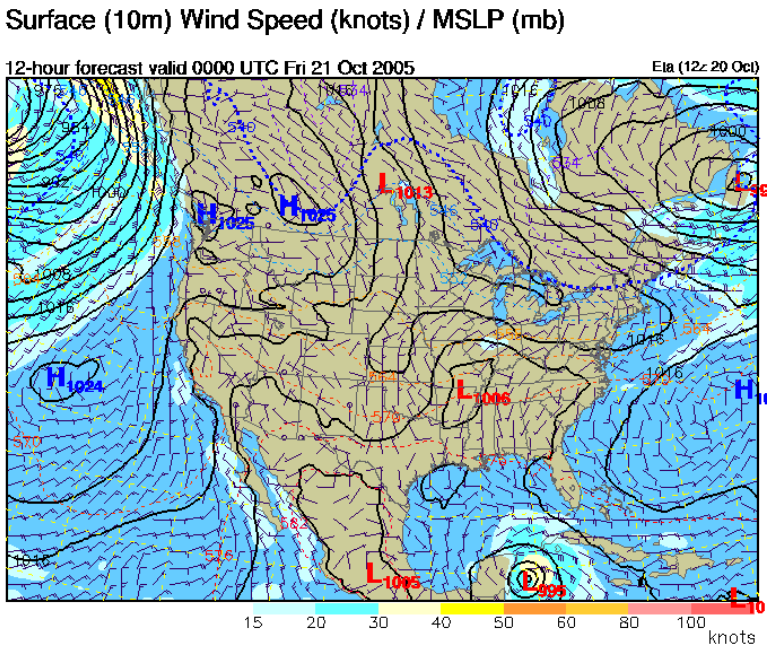
An example – Standard versus 4DWX model forecasts

Standard model forecast from National Weather Service

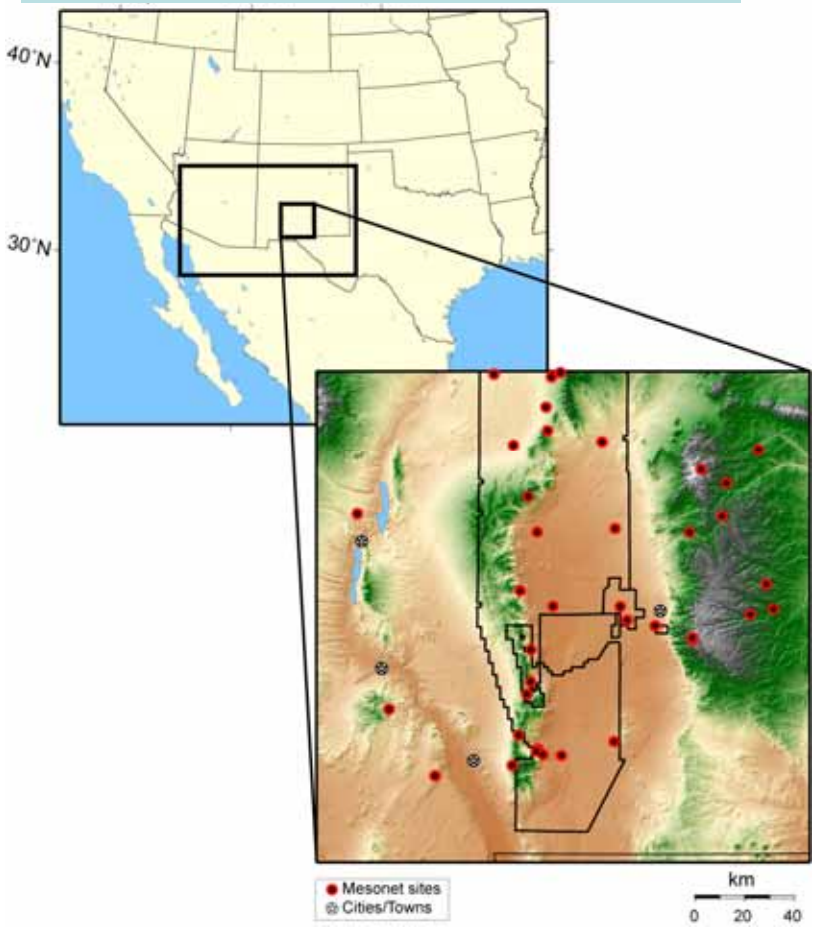


For example - model forecasts

Standard model forecast from National Weather Service

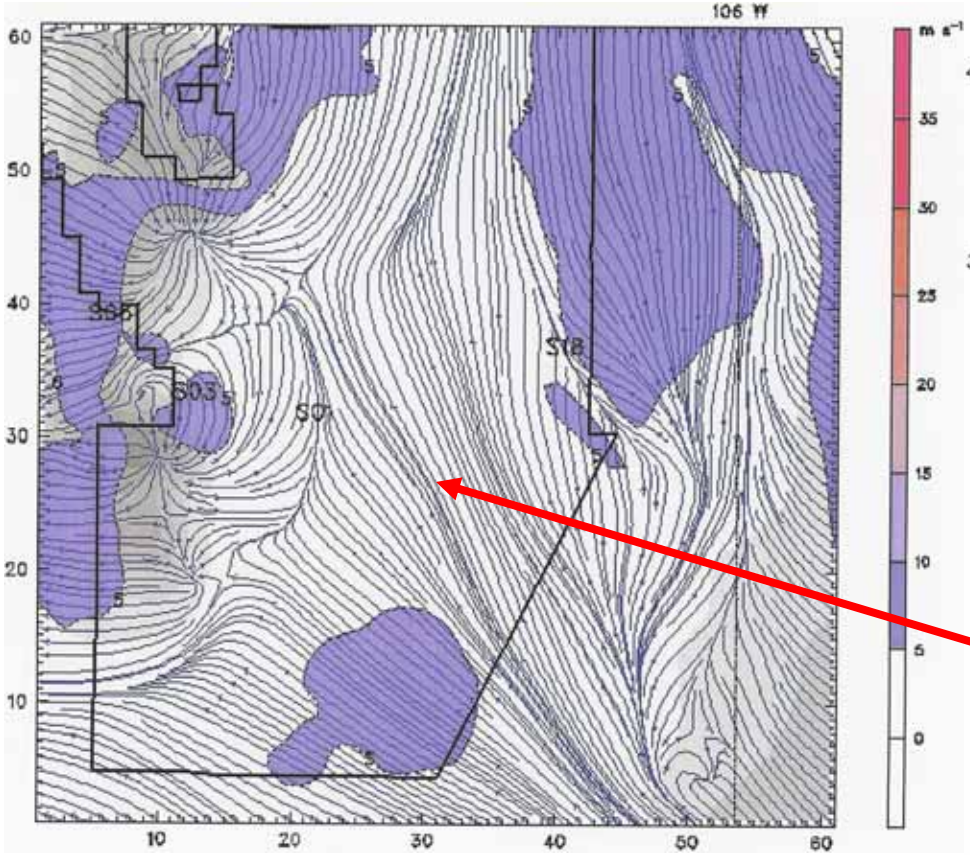


Current 4DWX model computational area for White Sands Missile Range



For example - model forecasts

Complex forecast wind-flow pattern near the surface – lines define wind direction



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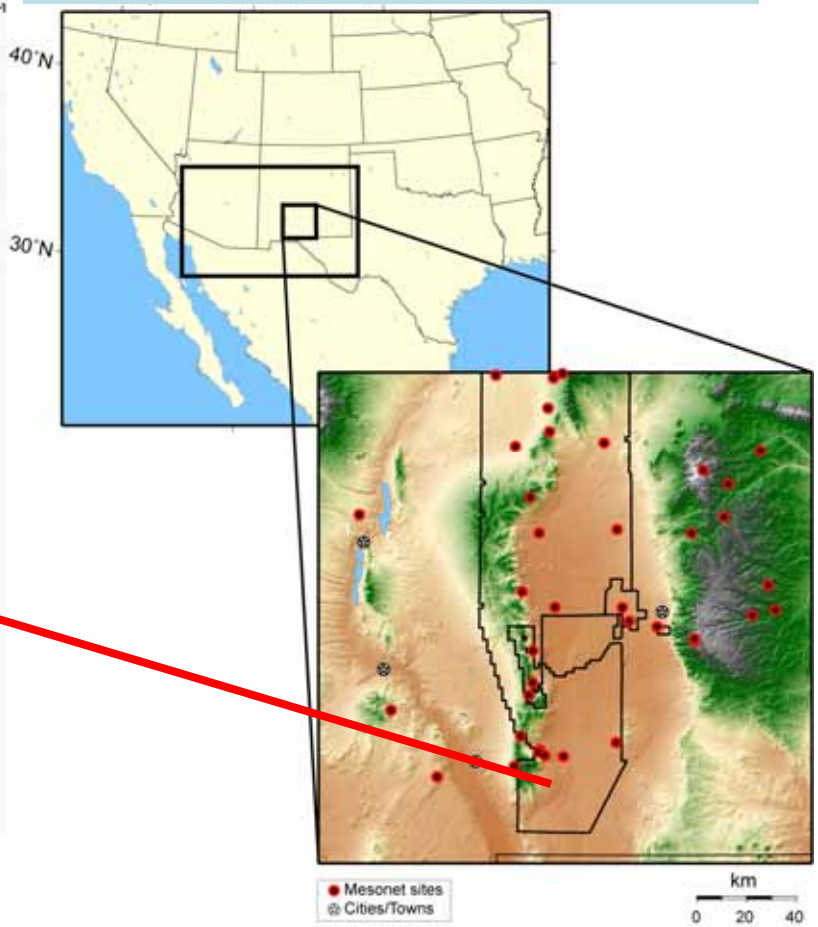


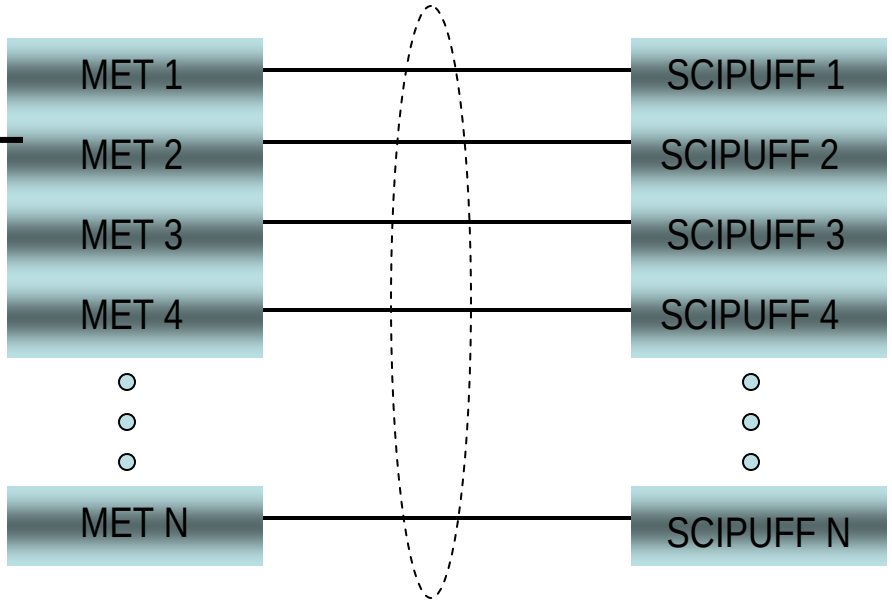
Why haven't standard products been able to serve ATEC's weather needs?

- Test ranges have specialized weather needs – e.g., boundary layer winds
- Models need to be especially high resolution because of nearby complex topographic and coastal forcing
- Weather models need to be closely coupled to special-applications models – transport and diffusion, parachute drift, sound propagation

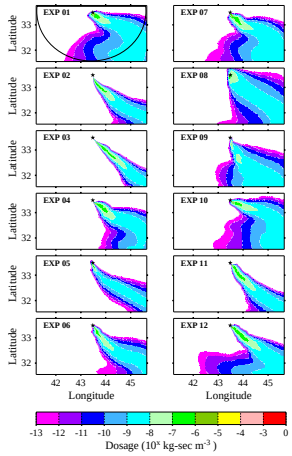
New High-Performance Computing Requirements for ATEC 4DWX System -- EXISTING EFFORTS --

- Ensemble prediction – multiple parallel model runs provide probabilistic forecasts to T&E customers
- 4DWX On The MOVE – graphical interface to weather model allows support of world-wide operational and virtual testing by non-experts
- Global Climatological Analysis Tool – constructs high-resolution analyses of regional climate for long-range test planning, at ranges or worldwide
- FCS/VPG Support – 4DWX model provides very-high-resolution atmospheric environment for virtual testing

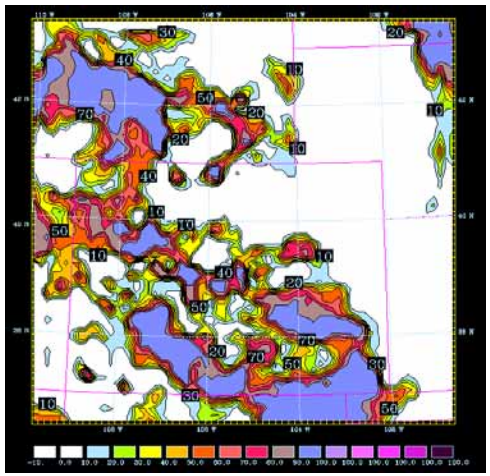
ATEC Ensemble Prediction



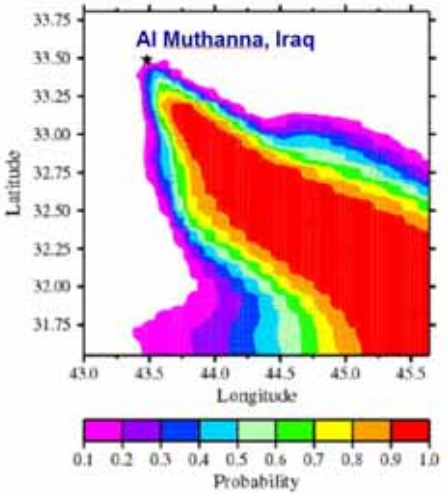
Plume ensemble output



Met. ensemble output: probability of winds > 5 m/s over Colorado



Probability of dosage exceedance



ATEC 4DWX On The Move

- Graphical interface is used to deploy operational weather modeling system
- Used to support special missions that are not covered by stationary range weather-modeling systems
- Example – WSMR support of missile launches in Hawaii

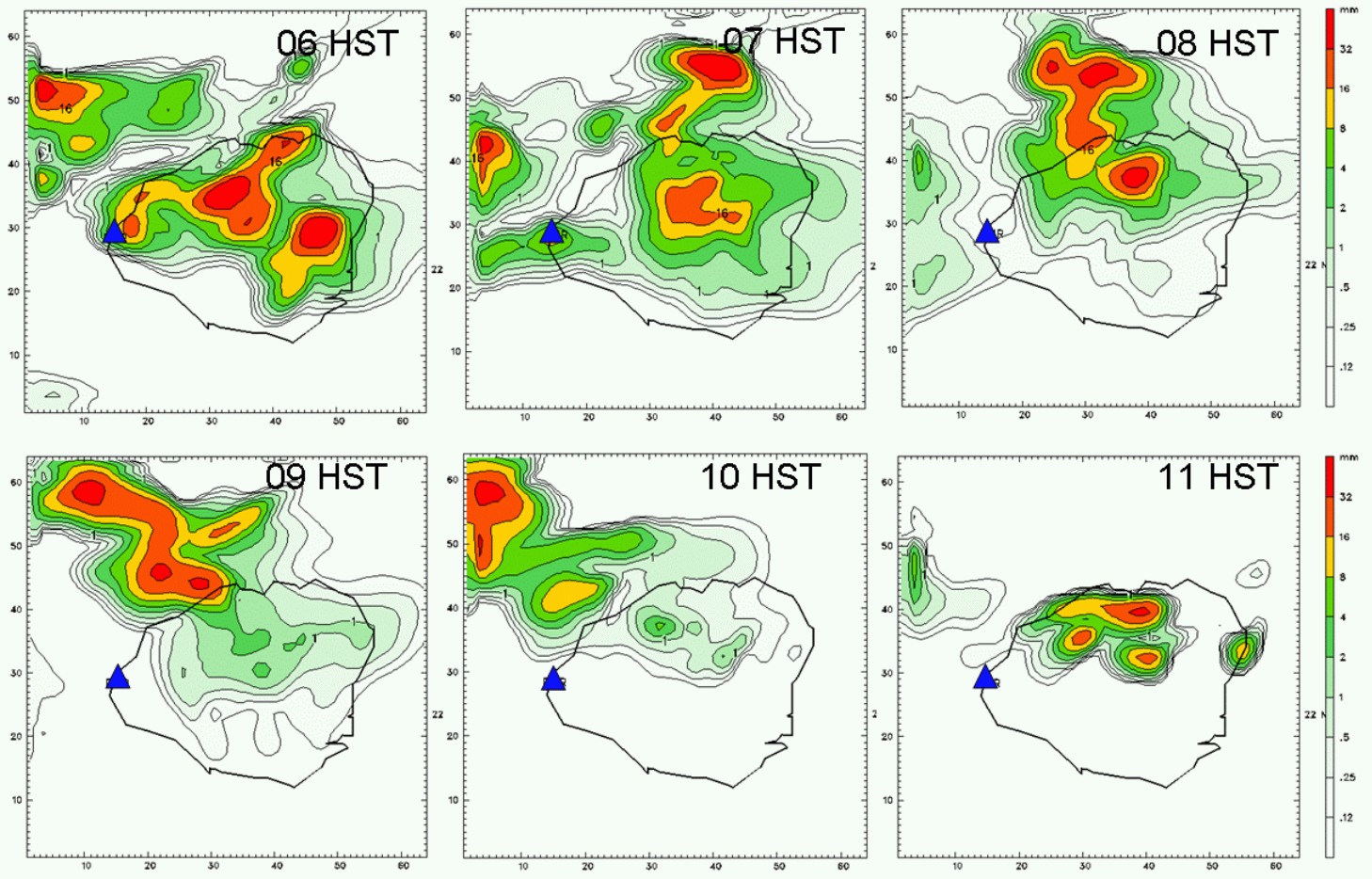
The Graphical Interface:

for quickly configuring and running the 4DWX forecast system

The situation in the early morning of 2 Feb 2005

- Mission: Rocket launch scheduled for 0800-1100 HST.
- Weather conditions at 0200 HST:
  - Persistent moist unstable flow over Kauai causing widespread thunderstorms.
  - Most of Kauai under a Flash Flood Warning.
- Situation looked highly unfavorable for a launch, but model was predicting a break in the rain between 0900 and 1100 HST.

The ATEC-model forecast from the previous evening: Heavy rain until about 0830 HST, followed by rapid clearing



(PMRF station is marked as blue triangles)

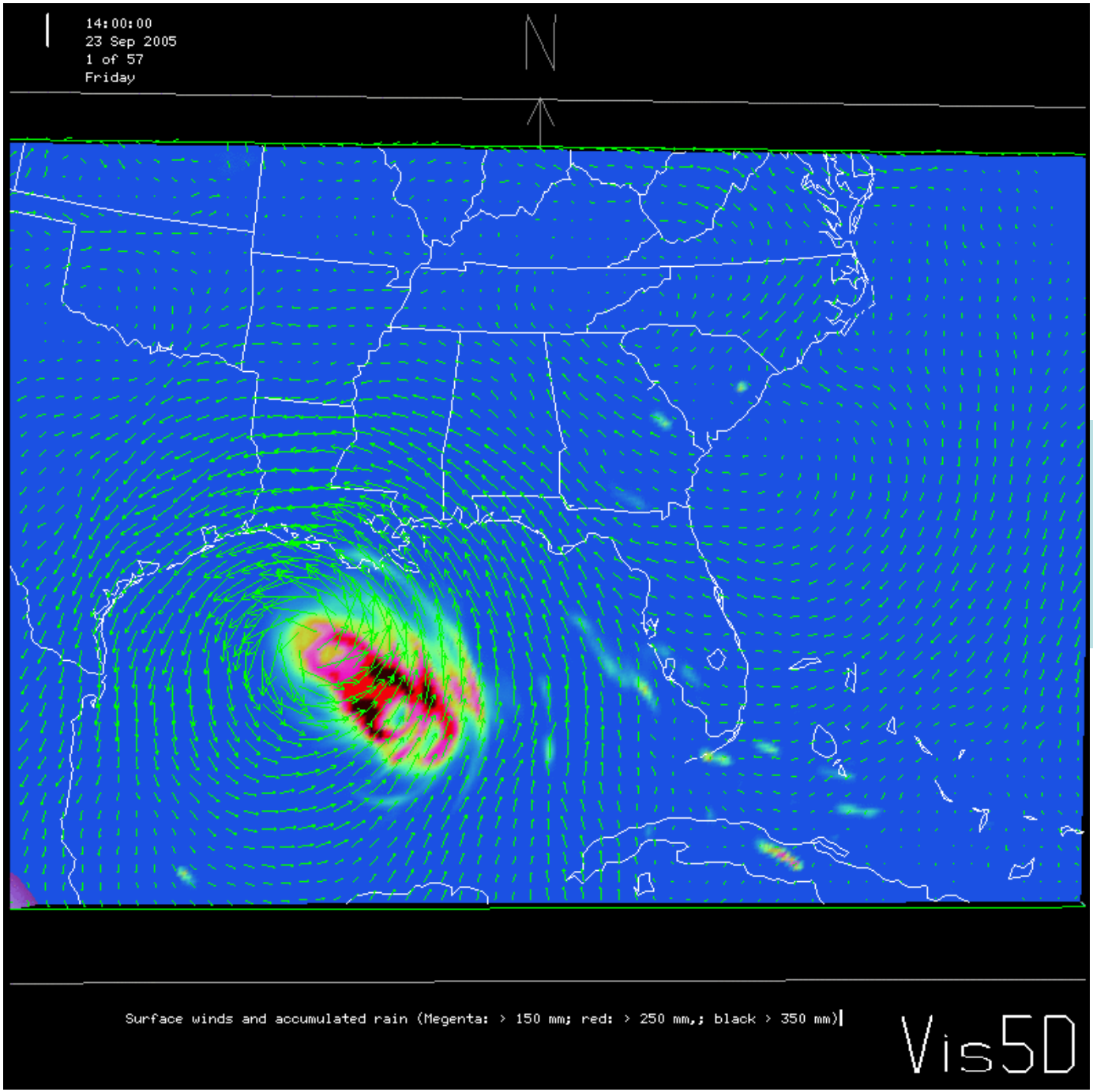
Case of Feb. 2 2005

Later that Morning (02 Feb 2005)

- 0600 HST: Little improvement in observed weather conditions.
- 0830 HST: National Weather Service radar indicated a break in the thunderstorm activity.
- 0900 HST: Rain ends and skies clear, as forecast by the model.
- Rocket successfully launched.

ATEC 4DWX On The Move – A National Asset

Supporting the Department of Homeland Security's forecast of the impact of Hurricane Rita on the National infrastructure



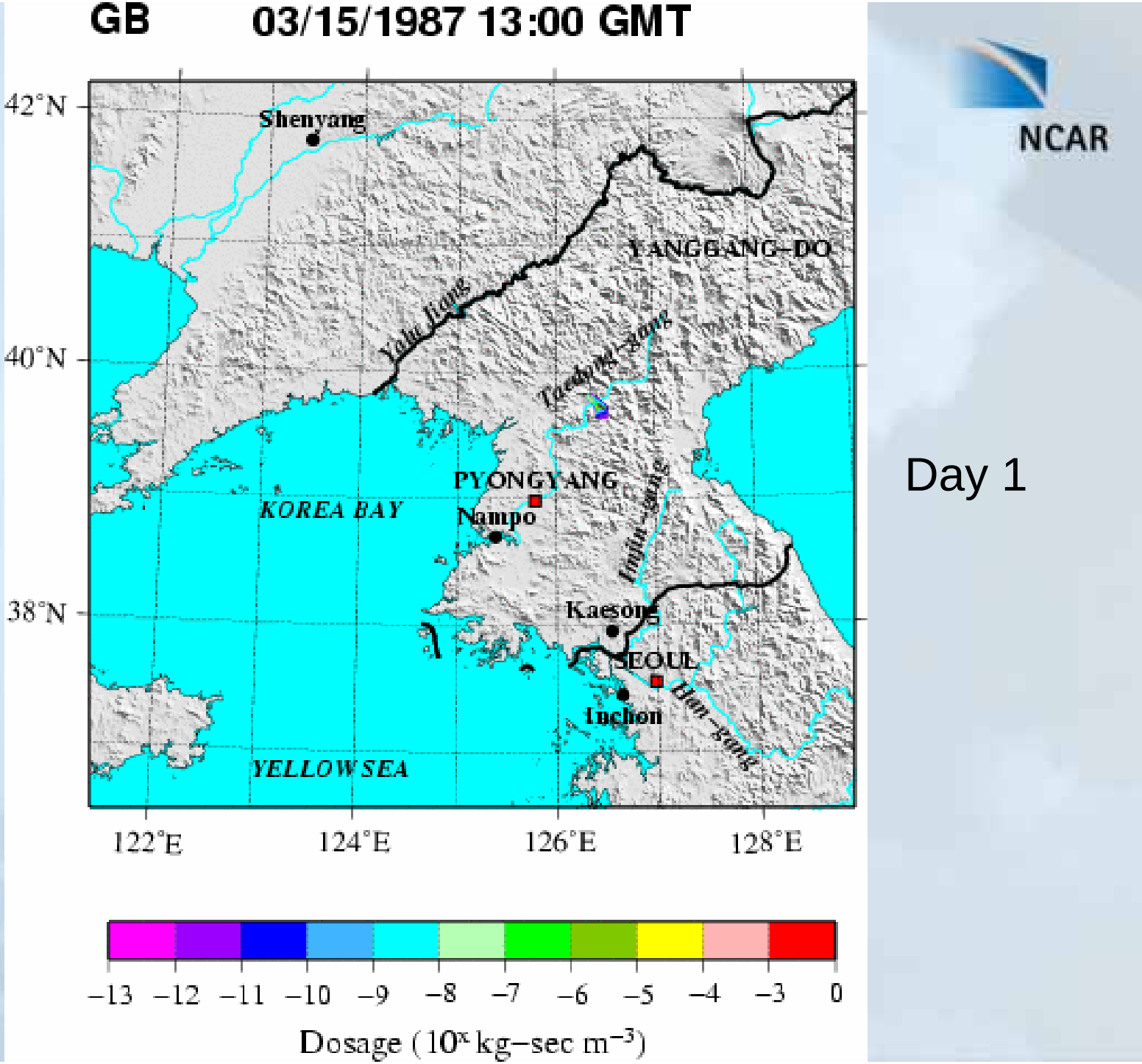
Colors – storm total precipitation

Global Climatological Analysis Tool

- Model is run for decades-long historical period to “downscale” available global climatological analyses
- The resulting high-resolution climatology of winds, temperature, etc. can be used for long range test planning
- The system can be used for range T&E or operational testing worldwide
- National Ground Intelligence Center now uses this system operationally; it will soon be deployed to ATEC ranges.

Example Of Application of Global Climatological Analysis Tool

What is the typical pattern of atmospheric transport of hazardous material over the Korean Peninsula in March?


GB
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42°N
40°N
38°N
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124°E
126°E
128°E
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YANGGANG-DO
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Taedong-gang
PYONGYANG
Nampo
KOREA BAY
Imjin-gang
Kaesong
SEOUL
Han-gang
Inchon
YELLOW SEA
−13 −12 −11 −10 −9 −8 −7 −6 −5 −4 −3 0
Dosage (10^x kg–sec m^{-3})

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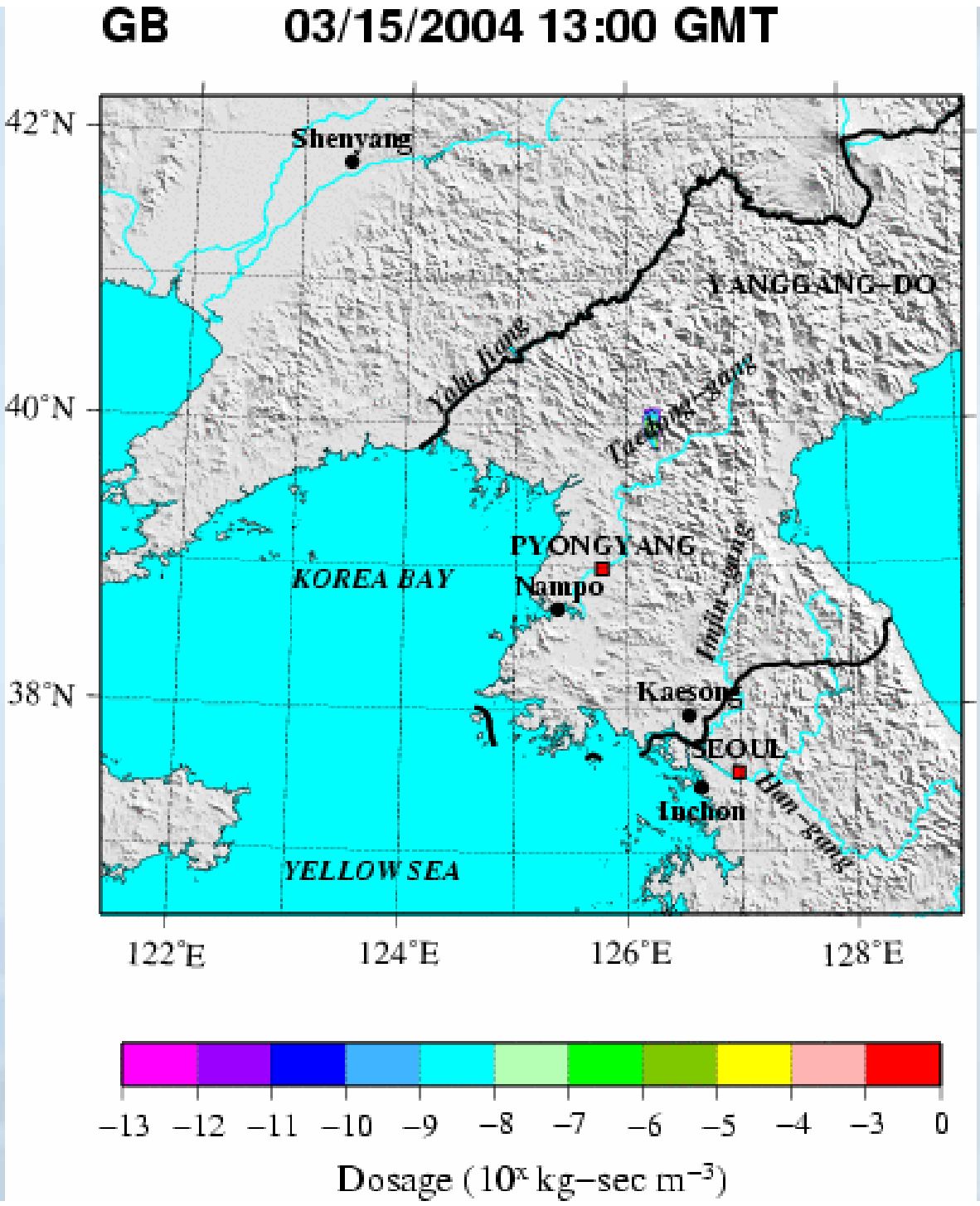
Day 1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Dosage (10^x kg–sec m^{-3})

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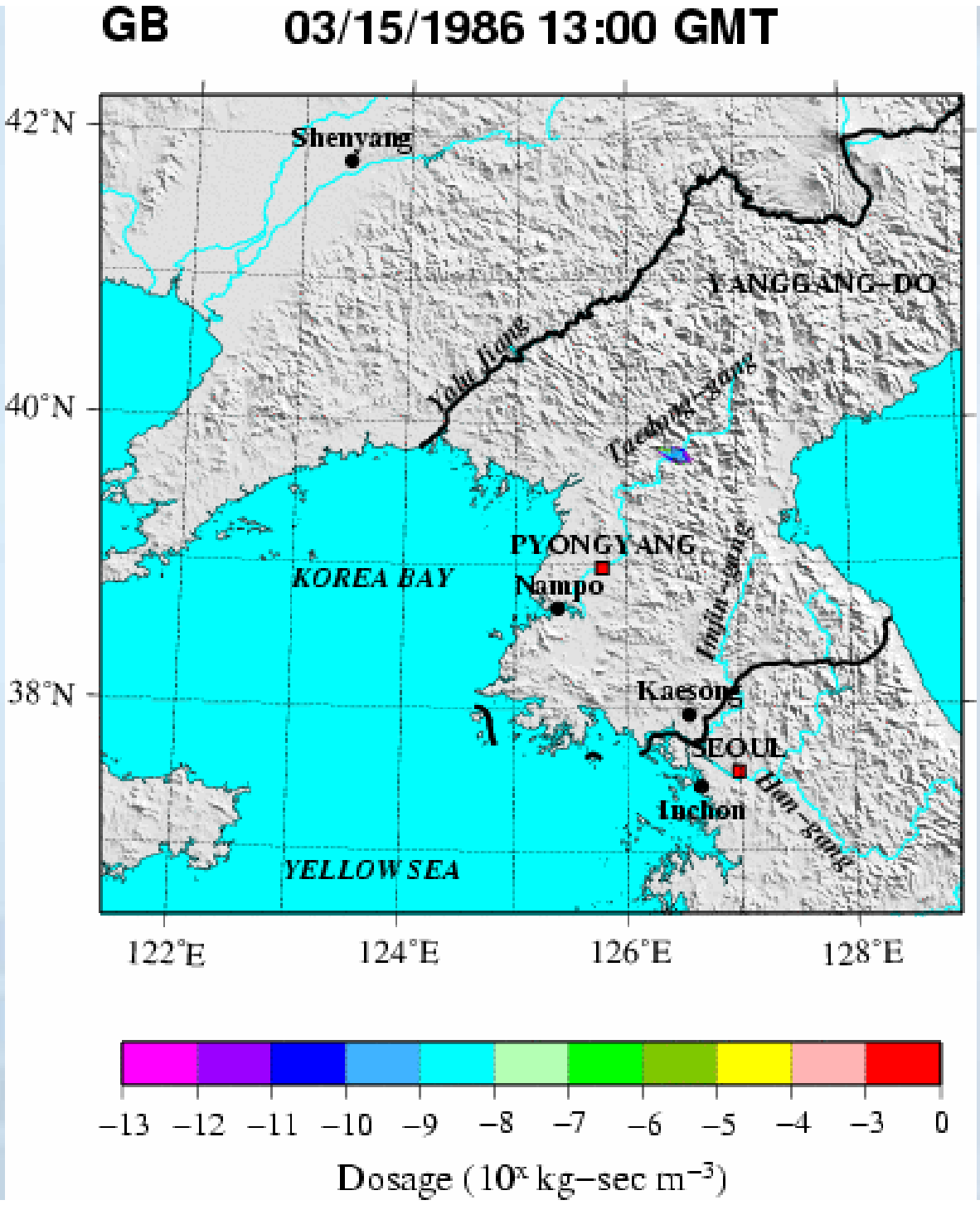
Day 2



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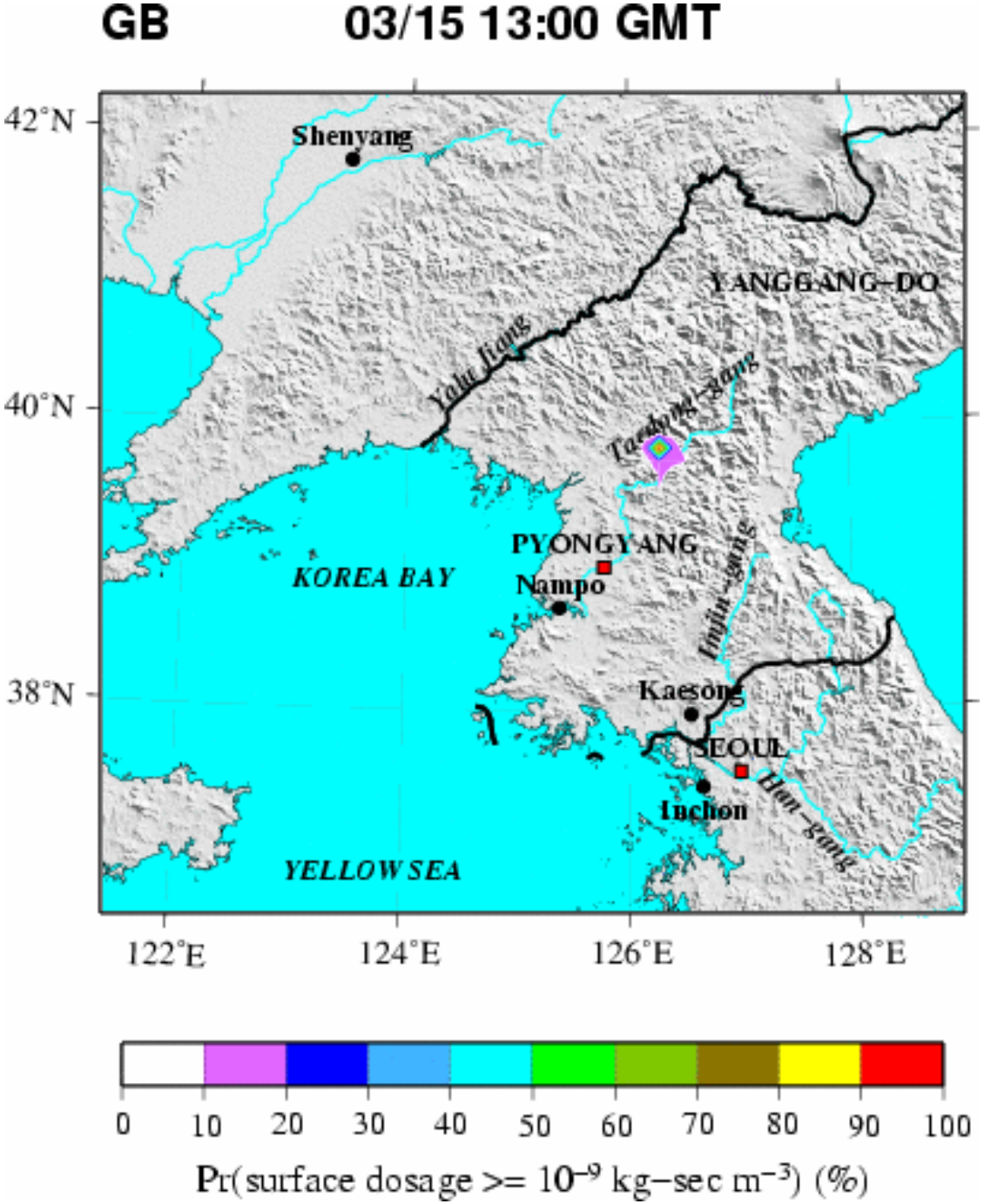
Day 3

etc.



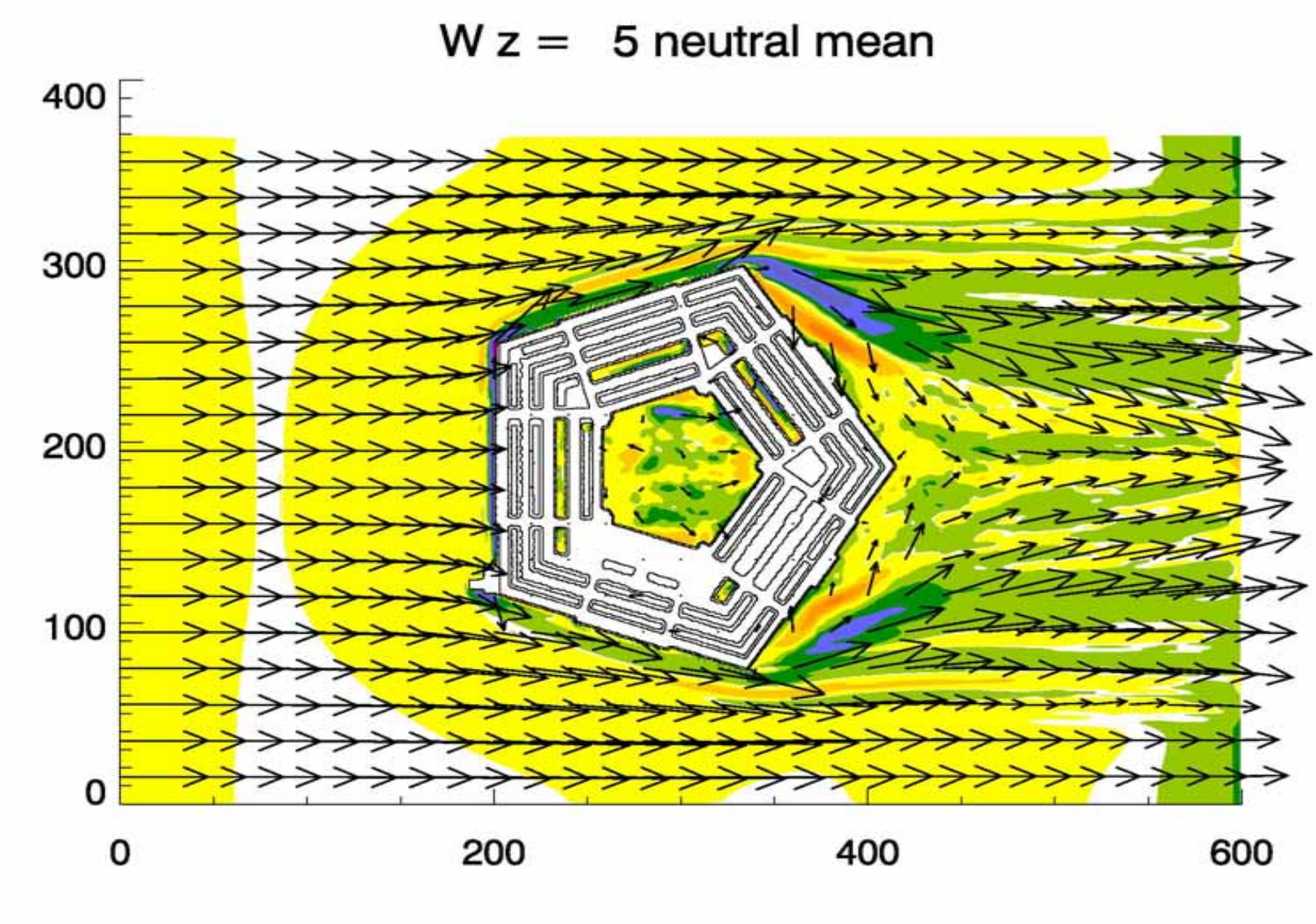
Probability of Exceeding a Dosage Threshold

Based on an ensemble from large number of case days in March

A New Extremely Computationally Intensive Direction for T&E Modeling

- Building-aware computational fluid dynamics models
- Application – Actual and virtual testing in urban settings
- Computationally intensive because grid increments must be about 2 meters to resolve building and street-canyon effects

Example – Modeled wind flow around the Pentagon



Summary of New Computationally Intensive Atmospheric Modeling in Support of T&E

- Ensemble prediction is providing probabilistic information to customers
- High-resolution atmospheric forecast systems can be deployed worldwide for operational testing
- Model-based very-high-resolution climatologies can be generated worldwide for long-range test planning
- FCS/VPG is beneficiary of high-resolution modeling and climatological-analysis capability
- ATEC 4DWX model is being coupled to building-aware urban models